Fire as a forest management tool: prescribed burning in the southern United States

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This article describes the use of prescribed burning as a forest and rangeland management tool in the southern United States.

The use of fire in the forests of the United States has come full cycle. Early settlers found Indians using fire in virgin pine stands and adopted the practice themselves to provide better access, to facilitate hunting, to reduce the threat of lightning fires and, most important, to improve the quantity and quality of forage for cattle. Destructive wildfires resulting from logging left millions of hectares of forest land in the southern United States devoid of trees, while the practice of annual burning to "freshen up" the range eliminated pine regeneration.

The increasing wildfire problem, coupled with the need for a fire-free interval of several years to allow the pines to become re-established, led many foresters to advocate the exclusion of all fire from the woods. Others, however, pointed out that fire might have a place in the management of many southern ecosystems, especially those dominated by longleaf pine. The misconceptions and controversy surrounding the deliberate use of fire to achieve resource management objectives have slowly been replaced by facts. As knowledge accumulated, the use of prescribed fire grew.

Prescribed burning may be defined as fire applied in a knowledgeable manner to wildland fuels on a specific land area under selected weather conditions to accomplish predetermined, well-defined management objectives.

Today prescribed fire is applied to a total area of approximately 3.25 million ha in the southern United States each year-- about half of which is burnt to achieve forest management objectives. Most of the remainder is for range and agricultural purposes.

REASONS FOR PRESCRIBED BURNING

There are many potential benefits to be gained from using prescribed burning as a tool in forest resource management, including the reduction of hazardous fuels; the preparation of sites for seeding or planting; the improvement of wildlife habitat; the disposal of logging debris; disease control; etc.

A single prescribed burn can achieve multiple benefits. For example, a well-planned burn can reduce fire hazard and also improve wildlife habitat, and almost any prescribed burn improves access. Prescribed fires are not always beneficial, however. When conditions are wrong, prescribed fire can severely damage the very resource it was intended to benefit. Prescribed fire is a complex management tool, and should be used only with care under controlled conditions.

Reduce hazardous fuels

Forest fuels accumulate rapidly in the pine stands of the Atlantic and Gulf coastal plains. In five to six years, heavy "roughs" (the live understorey and dead fuels that accumulate on the forest plains over time) can build up, posing a serious threat from wildfire to all forest resources. Prescribed fire is the most practical way to reduce dangerous accumulations of combustible fuels under southern pine stands.

The appropriate interval between prescribed burns for fuel reduction varies with several factors, which include the rate of fuel accumulation, past wildfire occurrence, and values at risk. The interval between fires can be as little as one year, although a three- or four-year cycle is adequate to attain most objectives.

***A STAND OF LONGLEAF PINE** prior to prescribed burning...*

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Dispose of logging debris

After harvest, unmerchantable limbs and stems are left either scattered across the area or concentrated at logging decks or delimbing gates, depending on the method of logging. This material is an impediment to both people and planting equipment. In stands that produce a large amount of cull material, the debris is often windrowed and burnt. This practice should, however, be avoided whenever practical, because of smoke management problems and the potential for site degradation. Broadcast burning (prescribed fire that burns over a designated area, generally in the absence of a commercially valuable overstorey, to consume debris that has not been piled or windrowed) is generally a much better alternative.

Prepare sites for seeding or planting

Prescribed burning is useful when regenerating southern pine by direct seeding, planting, or natural regeneration. On open sites, fire alone can expose adequate mineral soil and control competing vegetation until seedlings become established. Prescribed fire also recycles nutrients, making them available for the next timber crop.

For natural regeneration, knowledge of the anticipated seed crop and date of earliest seed fall is essential. If the seed crop is inadequate, burning should be postponed. Complete mineral soil exposure is not necessary or desirable; a thin layer of litter should remain to protect the soil. Generally, burning should be done several weeks before seed fall. Timing varies with species and locality.

Improve wildlife habitat

Prescribed burning is particularly appropriate for wildlife habitat management where loblolly, shortleaf, longleaf or slash pine is the primary overstorey species. Periodic fire tends to favour species that require a more open habitat. A mosaic of burnt and unburnt areas maximizes "edge effect", which promotes a large and varied wildlife population. The four primary southern game species, deer, dove, quail and turkey, all benefit from prescribed fire. Habitat preferences of several endangered species, including the Florida panther, the gopher tortoise, the indigo snake and the red-cockaded woodpecker, are also enhanced by burning.

Selecting the proper size, frequency and timing of burns is crucial to the successful use of fire to improve habitat. Plans should recognize biological requirements (such as nesting times) of the preferred wildlife species, and also consider the vegetative condition of the stand and, most important, the changes fire will produce in understorey status and species composition.

Manage competing vegetation

Unwanted species may crowd out or retard the growth of the primary crop, in this case pine. Furthermore, understorey trees and shrubs draped with dead needles and leaves act as ladder fuels, allowing a fire to climb into the overstorey crowns.

In most situations, total eradication of the understorey is neither practical nor desirable. The understorey can be managed with the judicious use of prescribed fire to limit competition with the primary species while, at the same time, providing browse for wildlife and increasing biodiversity.

Control insects and disease

Brownspot disease is a fungal infection that may seriously weaken and eventually kill longleaf pine seedlings. Once seedlings become infected, burning is the most practical method of disease control; if implemented properly it eliminates the diseased needles without killing the terminal bud. Prescribed burning also seems to reduce problems associated with *Fomes*

... AND THE SAME STAND
after prescribed burning to remove undergrowth

annosus root rot by altering the micro-environment of the forest floor. In the southern Appalachians, fire is being used in white pine seed orchards to destroy overwintering white pine cone beetles.

Improve forage for grazing

Low-intensity burns increase availability, palatability, quality and quantity of grasses and forbs. Dead material low in nutrient value is removed while new growth high in protein, phosphorus and calcium becomes readily available. Cattle congregate on recently burnt areas, so burn location and size must be carefully selected to prevent overgrazing. One commonly used system is to divide the range into three parts and burn one-third every year.

Enhance appearance

Prescription burning can also improve recreation and aesthetic values. For example, burning maintains open stands, produces vegetative changes, and increases numbers and visibility of flowering annuals and biennials. A practical way to maintain many visually attractive vegetative communities is through the periodic use of prescribed fire.

Improve access

Burning underbrush prior to the sale of forest products improves the efficiency of cruising, timber marking and harvesting. Removing accumulated material before harvesting also provides greater safety for timber markers and loggers, owing to better visibility and less underbrush.

Perpetuate fire-dependent species

Many plants have structural adaptations, specialized tissues or reproductive features that enable them to flourish in a fire-dominated environment. Many picturesque flowers, including several orchids currently listed as threatened or endangered, benefit from fire. Prescribed burning, however, does not automatically help perpetuate plant and animal species. The individual requirements of a species must be understood to enable the proper timing and fire intensity to be prescribed.

IMPROVED GRASSES FOR CONTROLLED GRAZING ***as a result of prescribed burning***

ENVIRONMENTAL EFFECTS

Prescribed burning has direct and indirect effects on the environment. Proper use of prescribed fire and evaluation of the benefits and costs of a burn require knowledge of how fire affects vegetation, wildlife, soil, water and air.

Effects on vegetation

Fire may injure or kill part of a plant or the entire plant, depending on how intensely the fire burns and how long the plant is exposed to high temperatures. In addition, such plant characteristics as bark thickness and stem diameter influence susceptibility to fire. Small trees are easier to kill than large ones.

Southern pine bark has good insulating qualities, and is thicker than the bark of most hardwood species. As a result, hardwood trees are generally much more susceptible to fire injury than are pines. Pine trees 10 cm or more in ground diameter have bark thick enough to protect the stems from damage by most prescribed fires. However, the crowns are quite vulnerable to temperatures above 58°C. Pine needles will survive exposure to 54°C for about five minutes, while similar needles exposed to 62°C for only a few seconds will die.

Very high temperatures are produced in the flames of burning forest fuels. Fortunately, the hot gases cool rapidly above the flame zone and are back to a few degrees above normal air temperature a short distance from a prescribed fire unless

CROWN SCORCH results when flames rise into the forest canopy

the wind is calm. Therefore, adequate wind should be present to help dissipate the heat and slow its rise into the overstorey canopy. Although southern pines generally survive severe crown scorch, growth is often retarded for a year or more.

Even though pine bark is a good insulator, cambial damage can occur from the extended smouldering of duff around the root collar. Such damage is especially likely in stands of previously unburnt, mature trees where a deep organic layer has accumulated. Whenever heat penetrates into the soil, feeder roots and beneficial soil organisms are likely to be killed.

In the United States, prescribed fire is generally not used in the management of hardwoods intended for harvest once a stand is established. Fire may not kill large hardwoods outright, but it will often leave fire scars which render the lower portion of the bole unmerchantable and provide entry to insects and disease.

Unwise use of fire may also alter species composition, but with adverse results, particularly when relying on natural regeneration of pine stands.

Effects on soil

Specific effects on soil may vary greatly. Frequency, duration and intensity of fire, as well as soil characteristics, must be considered. Prescribed burning in the southern United States normally causes little or no detectable change in the amount of organic matter in surface soils. In fact, slight increases have been reported on some burnt areas. Prescribed underburns will not cause changes in the structure of mineral soil, because the elevated temperatures are of brief duration. However, burning piled or windrowed debris, or burning when fuel and/or soil moisture conditions are extremely low, may elevate temperatures long enough to ignite organic matter in the soil as well as alter the structure of soil clays.

As a stand matures, an increasing proportion of the nutrients on the site become locked up in the vegetation and are unavailable for further use until plants die and decompose. Low-intensity fires speed up this recycling process, returning nutrients to the soil where they are again available to plants. Under many conditions, burning increases nitrogen fixation in the soil, which more than compensates for any direct nitrogen loss to the atmosphere during the fire. Available phosphorus levels are increased on sandy soils and basic cations are released which might have a significant impact on the effects of acid rain by neutralizing the acidic components in precipitation.

A major concern of the forest manager is how fires affect surface runoff and soil erosion. Care must be taken when clearcut logging slash is burnt on steep slopes. Until grass and other vegetation cover the site, surface runoff and soil erosion may occur. The burning phase of the "fell and burn" site preparation 'technique, commonly used in the upper Piedmont and mountain areas of the southern United States, must be completed by mid-September to allow herbaceous plants to seed in and provide a winter ground cover.

Burning should not be undertaken if exposure of highly erosive soils is likely.

Effects on water

The main effect of prescribed burning on the water resource is the potential for temporarily increasing runoff of rainfall. When surface runoff increases after burning, it may carry suspended soil particles, dissolved inorganic nutrients and other materials into adjacent streams and lakes, reducing water quality. Problems can be avoided by leaving unburnt buffer strips adjacent to streams and lakes and by ensuring that the duff layer is not consumed.

Rainwater leaches the mineralized nutrients out of the ash and into the soil. In sandy soils, leaching may also move minerals through the soil layer into the ground water before they can be captured by new plant growth. It appears that species inhabiting southeastern fire-dominated ecosystems have developed traits that enable them to retain and utilize fire-released nutrients more efficiently.

Effects on air

Prescribed fires can have a deleterious effect on air quality, particularly through reduced visibility. Air quality on a regional scale is affected only when many hectares are burnt on the same day. Local problems are more frequent and occasionally acute, owing to the large quantities of smoke that can be produced in a given area during a short period of time, especially when fuels are wet and combustion is incomplete.

The effects of smoke can be mitigated by burning on days when smoke will blow away from smoke-sensitive areas. Any smoke impact downwind must be considered before lighting the fire.

Effects on human health and welfare

Smoke can have negative short- and long-term health effects. Fire management personnel who are exposed to high smoke concentrations often suffer eye and respiratory system irritation. Under some circumstances, exposure to high concentrations of carbon monoxide at the combustion zone can result in impaired alertness and judgement.

More than 90 percent of the particulate emissions from prescribed fire are small enough to enter the human respiratory system. These particles can contain hundreds of chemical compounds, some of which are toxic. Repeated, lengthy exposure even to relatively low smoke concentrations can contribute to respiratory problems and cancer. But the risk of developing cancer from exposure to prescribed fire has been estimated to be less than one in a million.

Effects on wildlife

The major effects on wildlife are indirect and pertain to changes in food and cover. Prescribed fires generally increase edge effect and amount of browse, thereby improving conditions for deer and other wildlife. Burning can improve habitat for marshland birds and animals by increasing food production and availability.

The potential negative effects of prescribed fire on wildlife include destruction of nesting sites and, in rare instances, direct mortality. However, these can be avoided by utilizing appropriate timing and burning techniques. The practice of lighting all sides of a burn area (see section on ring firing, page 35) is a primary cause of animal entrapment and has no place in prescribed burning. It also results in unnecessary tree damage as the flame fronts merge in the interior of the area.

Prescribed burning does not benefit fish habitat, but it can have adverse effects if streamside vegetation is removed, thereby allowing water temperatures to increase.

WEATHER AND FUEL CONSIDERATIONS

A general understanding of the separate and combined effects of weather elements on fire behaviour is needed to plan and execute a burn properly. Wind, relative humidity, temperature, rainfall, and airmass stability are the most important elements to consider. All these factors influence fuel moisture, which is the most critical factor governing success of a burn.

Wind

Prescribed fires behave in a more predictable manner when windspeed and direction are steady. For underburning, the preferred range for windspeed in the stand is 2-5 km/hr (at eye level) for most fuel and topographic situations. With high winds, heading fires spread too rapidly and become too intense. On the other hand, enough wind must be present to give the fire direction and to keep the heat from rising directly into tree crowns. Of perhaps greater importance than windspeed is the length of time the wind blows from one direction.

The most critical areas with regard to fuel and topography should be burnt when wind direction is steady and persistent. Relatively easy burns can be conducted under less desirable wind conditions. Topography, and local effects such as stand openings and roads, may have a bearing on favourable wind conditions and should be considered when planning a burn.

In the case of debris burning in open areas, because there is no overstorey to protect, wind is not needed to cool the heated air. However, from a smoke management standpoint, the stronger the wind the better the dispersion-- provided there are no downwind smoke-sensitive areas. During broadcast burning, eye-level winds of more than 5-6 km/hr can create containment problems if a heading fire is used. With piled or windrowed debris, eye-level winds of 12-16 km/hr can be tolerated.

Relative humidity

Relative humidity is an expression of the amount of moisture in the air compared

SOIL EROSION can be a negative consequence of burning on steep slopes

with the total amount the air is capable of holding at that temperature and pressure. Preferred relative humidity for prescribed underburning varies from 30 to 55 percent. When relative humidity falls below 30 percent, prescribed burning becomes dangerous. Fires are more intense, and spotting (fires ignited outside the desired area by falling brands) is much more likely. When the relative humidity is higher than 60 percent, a fire may leave unburnt islands or may not burn hot enough to accomplish the desired result.

With regard to debris burning, the response to changes in relative humidity is much more rapid in fine dead fuels suspended above the ground than in those that are part of the litter layer. These elevated needles and other suspended dead materials are not in direct contact with the damp lower litter and are more exposed to the sun and wind.

In the burning of piled debris, once the larger-diameter fuels ignite, increases in relative humidity have little effect on fire behaviour during the active burning phase. Very low humidity, however, promotes spotting and increases the likelihood of fire spreading between piles.

Temperature

As noted earlier, the average instantaneous lethal temperature for living tissue is about 62°C. Air temperatures below 15°C are recommended for winter underburns because more heat is needed to raise foliage or stem tissue to lethal temperature levels. However, when the objective is to control undesirable species, growing-season burns with ambient air temperatures above 25°C are recommended. These conditions increase the likelihood of reaching killing temperatures in understorey stems and crowns. Of course, the overstorey pines must be large enough to escape injury.

Temperature strongly affects moisture changes in forest fuels. High temperatures help dry fuels quickly. When fuels are exposed to direct solar radiation they become much warmer than the surrounding air. Moisture will move from the warmer fuel to the air even though the relative humidity of the air is high. Temperatures below freezing, on the other hand, retard fire intensity because additional heat is required to convert ice to liquid water before it can be vaporized and driven off as steam. Consequently, it does not take much moisture under these conditions to produce a slow-moving fire that will leave unacceptably large areas unburnt.

Cleared areas are often burnt when ambient air temperatures are high. There is no overstorey to worry about, and surface heating from direct sunlight usually increases mixing height, which in turn promotes smoke dispersion.

Rainfall and soil moisture

Because rainfall affects both fuel moisture and soil moisture, basic information on the amount of rain falling on the area to be burnt is essential. The importance of adequate soil moisture cannot be overemphasized. Damp soil protects tree roots and micro-organisms. Even when burning is undertaken to expose a mineral soil seed-bed, it is desirable to leave a thin layer of organic material to protect the soil surface. Burning should cease during periods of prolonged drought and resume only after a soaking rain.

Generally, rain has a greater impact on fuel moisture in cleared areas than under a stand. However, fuels also dry much more quickly in cleared areas because of increased sunlight and higher windspeeds. This differential drying can often be used to advantage from a fire-control standpoint. Burning a cleared area several days after a hard rain while fuels in the surrounding forest are still damp assures good soil moisture and helps to prevent the fire spreading beyond its designated boundaries.

Fine-fuel moisture

Fine-fuel moisture is strongly influenced by rainfall, relative humidity and temperature. The preferred range in fine-fuel moisture of the upper litter layer (the surface layer of freshly fallen needles and leaves) is from 10 to 20 percent. Burning when fine-fuel moisture is below 6 percent can result in damage to plant roots and even the soil. When fine-fuel moisture approaches 30 percent, fires tend to burn slowly and irregularly, often resulting in incomplete burns.

One simple test that will give a rough estimate of the moisture content of the upper litter layer is to pick up a few pine needles and individually bend each in a loop. If the needles snap when the width of the loop is about 1/2-1 cm, their moisture content is between 15 and 20 percent. If they do not snap in two, they are too wet to burn well. If they crumble into small pieces, they are exceedingly dry and even if the lower litter is moist, the fire may cause damage to the soil layer and be difficult to control. However, the only sure way to determine moisture levels is to take a sample and oven-dry it.

Lower litter should always be checked before burning to make sure it feels damp. This will help ensure that some remains, even though charred, to leave a protective covering over the soil.

In the case of debris-burning, harvested areas should be burnt when fuels are dry. They will ignite more easily and burn more quickly and completely. To minimize soil damage, it is better to burn debris as it lies (broadcast burning) rather than in piles or windrows. However, if the burn objective is to consume larger fuels (more than 4-5 cm in diameter), piling will probably be necessary. Allow fresh logging debris to cure for several weeks before piling because drying conditions are extremely poor in the middle of a pile, especially if it is compacted or contains much dirt.

Airmass stability and atmospheric dispersion

Atmospheric stability is the resistance of the atmosphere to vertical motion. A prescribed fire generates vertical motion by heating the air. If the atmosphere is unstable, the hot combustion products will rise rapidly because of the large temperature difference between the smoke and the surrounding air. The column will continue to build in height as long as it remains relatively stationary and is heated by new combustion products faster than it is being cooled. The stronger the convective activity, the stronger the indrafts into the fire. This effect increases fire intensity by producing even stronger convective activity. Eventually spotting, crowning and other indicators of erratic fire behaviour develop. With adequate planning, this situation should not develop during underburning.

When the atmosphere is stable, its temperature decreases slowly as altitude increases. The old adage that hot air rises is true, but only as long as it is warmer than the surrounding air. Thus, stable air tends to restrict convection column development and holds combustion products closer to the ground.

Strong convection over cleared areas burnt for site preparation or slash disposal helps vent smoke into the upper atmosphere. A well-developed convection column produces strong indrafts which help confine this type of fire to its predesignated area. Care must be taken to ensure that all burning materials entrained into the convection column burn out before being blown downwind and dropping to the ground to act as firebrands.

FIRING TECHNIQUES

Various firing techniques can be used to accomplish burning objectives. The technique chosen must be correlated closely with fuels topography and weather factors so as to ensure goals are met while preventing undesired damage to forest resources.

According to behaviour and spread, fires move with the wind (heading fire), against the wind (backing fire) or at right angles to the wind (flanking fire). Heading fire is the most intense because of its faster spread rate, wider flaming zone and longer flames. Backing fire is the least intense, having a slow spread rate regardless of windspeed. Flanking fire intensity is intermediate.

Backing fire

A backing fire is started along a baseline such as a road, plough line, stream or other barrier and allowed to back into the wind. Backing fire is the easiest and safest type of prescribed fire to use, provided windspeed and direction are steady. It produces minimum scorch and lends itself to use in heavy fuels and young pine stands.

Disadvantages include the slow progress of the fire and the increased potential for feeder-root damage with increased exposure to heat if the lower litter is not moist enough.

Strip-heading fire

In strip-head burning, a series of lines of fire are set progressively upwind of a fire-break in such a manner that no individual line of fire can develop to a high energy level before it reaches either a firebreak or another line of fire. The distance between ignition lines is determined by the desired flame length.

Strip-heading fires permit quick ignition and burnout and provide for smoke dispersal under optimum conditions. However, higher intensities will occur wherever lines of fire burn together, increasing the likelihood of crown scorch.

Occasionally, on areas with light and even fuel distribution, a single line of heading fire may be set along the upwind edge and allowed to move over the entire area to accomplish the objective better. However, caution must be exercised to ensure that this type of fire does not escape control.

Flanking fire

The flanking fire technique consists of treating an area with lines of fire set directly into the wind. The lines spread at right angles to the wind. This technique requires considerable knowledge of fire behaviour, particularly if used by itself. It is used quite often to secure the flanks of a strip-heading fire or backing fire as it progresses. It is sometimes used to supplement a backing fire in areas of light fuel or under particularly humid weather conditions. It

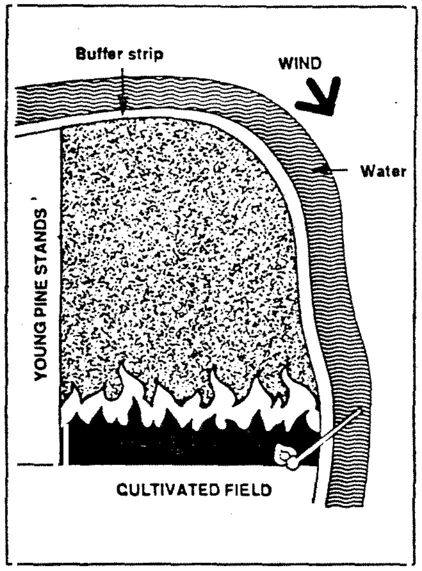


FIGURE 1
backing fire technique

is useful on a small area or to facilitate burning a large area in a relatively short time when a line-heading fire would be too intense. It should be noted that this method of firing can stand little variation in wind direction and requires expert coordination and timing.

Point source fires

When properly executed, a grid of spot ignitions will produce a fire with an intensity much greater that of a line-backing fire, but somewhat less than that of a line-heading fire. Timing and spacing of the individual ignition spots are the keys to the successful application of this method.

First a line-backing fire is ignited across the downwind side of the block and allowed to back 3-6 m into the block to increase the effective width of the control line. Successive lines of spots are then ignited upwind of the backing fire until the entire block has been ignited.

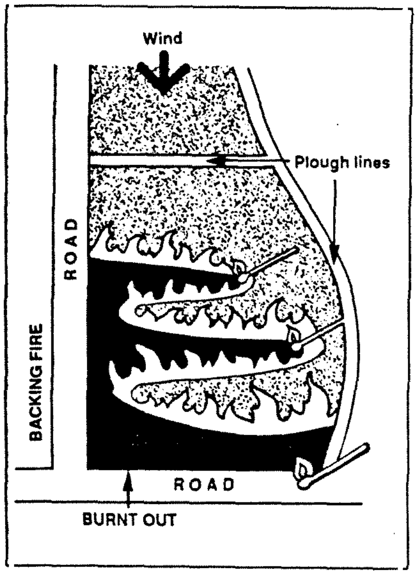
To minimize crown scorch, ignition-grid spacing is selected to allow the spots along a line to head into the rear of the spots along the downwind line before the flanks of the individual spots merge to form a continuous flame front. The merger of successive ignition lines thus takes place along moving points rather than along a whole line at the same time.

Of course, the closer the spacing, the more merging points there are. It is important to remember that a large number of small fires burning simultaneously can produce the same kind of explosive convective energy as a single large fire. Thus the balancing act between spacing and timing has to be continually adjusted as fire behaviour reacts to both temporal and spatial changes in fuel and weather.

Centre and circular (ring) firing

Ring firing is useful on cut-over areas where a hot fire is needed to reduce or eliminate logging debris prior to seeding or planting. It works best when winds are light and variable, or completely calm. This procedure should never be used for underburning, because of the likelihood of severe damage to trees and wildlife as the flame fronts merge.

FIGURE 2
strip-heading fire technique



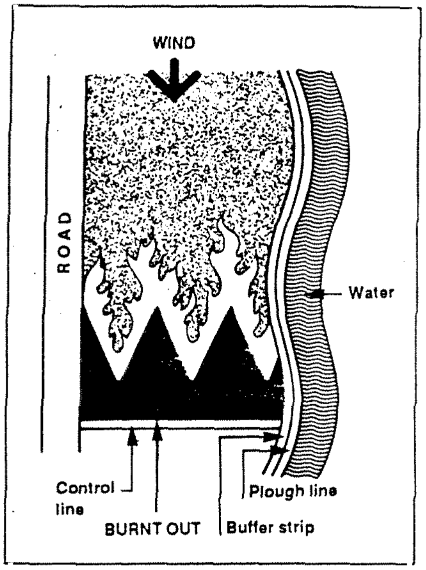


FIGURE 3
flanking fire technique

As with other burning techniques, the downwind control line is the first to be lit. Once the baseline is secured, the entire perimeter of the area is ignited and the flame fronts are allowed to converge. One or more spot fires are often ignited near the centre of the area and allowed to develop before the perimeter of the block is ignited. The convection caused by these interior fires creates indrafts that help pull the outer lines of fire toward the centre.

Pile and windrow burning

Logging debris should be broadcast-burnt whenever possible. Sometimes, however, the volume of large material necessitates piling in order to prolong residence time on a restricted area, thereby promoting consumption of the larger materials. Although it generally costs slightly more to construct circular piles than to windrow, piles are by far the better choice.

Windrowing can reduce site quality by removing topsoil. The area beneath the windrows is often lost to production because the debris is rarely consumed completely and what remains makes replanting difficult or even impossible. Even when windrows contain well-spaced breaks, they can still present a barrier to equipment and wildlife. Circular piles, on the other hand, do not restrict access: planting is easier, burning is safer, and smoke problems are significantly reduced.

THE BASICS OF A PRESCRIBED BURN

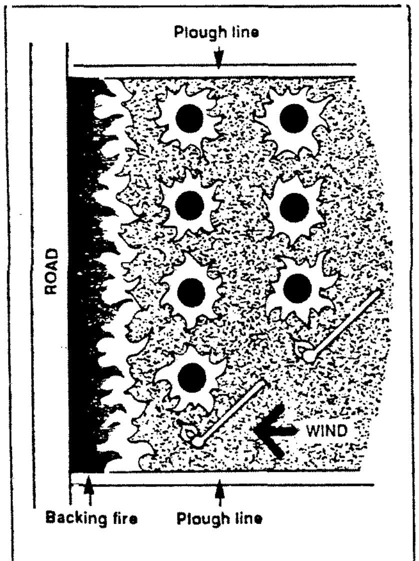
The specifics of a prescribed fire will vary with the site and weather conditions and management objectives. However, some general guidelines can be given.

Planning

The first step toward a successful prescribed burn is a written plan prepared by an expert for each area to be burnt. A prepared form with space for all needed information is best.

The plan should detail the reasons for prescribing a fire, for example to prepare the seed-bed, reduce the hazard of wildfire, or improve forage. In addition, the plan should contain a specific quantifiable objective: how much area should be burnt; what type of fire intensity is desired; how much litter should be left; etc.

FIGURE 4
point source fire technique



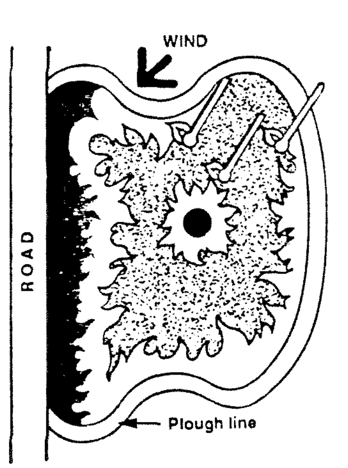


FIGURE 5
centre and circular (ring) fire technique

Specific instructions for firing and holding a burn are a key part of the plan. They should consist of a narrative section and a detailed map. The map should show the boundaries of the planned burn; topography; control lines; anticipated direction of the smoke plume; smoke-sensitive areas; land use in adjacent areas; location of labour and equipment, both for the burn itself and for emergency support if needed; etc.

The narrative should describe the firing technique, ignition pattern and planned ignition time and duration; the labour and equipment needed for setting, holding, patrolling and managing the fire; and instructions for all personnel.

Preparation

Preparation consists of all the steps necessary in making the area ready for firing, as well as ensuring that all needed tools and equipment are in operating order and ready to go. Good pre-burn preparation is essential in realizing maximum net benefits at acceptable cost.

The pre-burn work is often done by a crew consisting of a leader, a tractor operator and a clean-up person. The job is to locate and establish control lines to accomplish the objectives of the burning plan best. To do this job skilfully, the preparation crew must have full information on the burn objectives, site conditions and weather elements. The control lines should use natural barriers like existing roads and cultivated fields as much as possible. Ploughing should be kept to a minimum and on contour lines wherever possible. Control lines should be placed to create logical, one-day burns.

Any material that could carry fire across the control lines, for example vines and overhanging brush, should be removed. In addition, areas of exposed soil below burn areas on steep terrain should be seeded to prevent soil erosion caused by increased runoff after the burn. Finally, the location of all control lines should be transferred to the burn map, with special notations about zones of high risk.

Executing the burn

Adequate planning and preparation means that when desired weather conditions occur, burning can be undertaken. In the southern United States, a prescribed burning crew comprising a boss and three to six others can easily handle a burn of up to 100 ha. Such a crew often consists of two or three torch operators equipped with hand-tools and a tractor operator with a plough unit for emergency use. A second vehicle is necessary for large area burns to permit maximum mobility and safety of personnel. Radios for communication are also essential for a large burn. Chainsaws are useful additions to the basic equipment supply.

The burning boss should have the crew ready to fire the area as early in the day as conditions permit, leaving maximum time for mop-up and patrol of the lines. Normally, it is best to plan to complete burns in a single day.

Before beginning, the burning boss must ensure that the crew has the proper clothing and safety equipment, including long-sleeved fire-resistant clothing, leather boots with non-skid soles, safety glasses, hard hat, gloves, and a supply of drinking-water. The first step in actual burning is to test fire and smoke behaviour with a small fire; this is the time to cancel the burn if observed behaviour does not match predictions. If all conditions are within acceptable limits, the burning boss alerts the crew and begins the firing sequence. During the burning operation, the team must be alert to site conditions and be prepared to change burning techniques or even plough out the fire if an emergency arises. The perimeter of the area must be patrolled constantly during the operation and thereafter, until there is no further danger of fire escape or smoke problems.

Evaluation

The purposes of a burn evaluation are to determine how well stated objectives were met and to gain information to be used in future operations. Questions to be considered in an evaluation include: Was pre-burn preparation properly done? Were objectives met? Was the burning plan adhered to? Were changes documented? Were weather conditions, fuel conditions, fire behaviour and smoke dispersion within planned limits? What were the effects on soil, air, vegetation, water and wildlife? Was fire confined to the intended area? Was the burning technique correct? Were costs commensurate with benefits derived? How could similar burns be improved? An initial evaluation should be made immediately after the burn, perhaps the following morning. A second evaluation should be made during or after the first post-fire growing season.

CONCLUSION

Fire is neither innately destructive nor constructive; it simply causes change. Whether these changes are viewed as desirable or not depends upon their compatibility with overall objectives. In the southern United States resource managers have learned to manipulate fire timing and intensity to induce changes in plant and animal communities that meet their needs, and those of humankind in general, in an environmentally acceptable manner. ◆

Bibliography

Abercrombie, J.A. & Sims, D.H. 1986. Fell and burn for low-cost site preparation. *Forest Farmer*, 46(1): 14-17.

Boyer, W.D. 1987. Volume growth loss: a hidden cost of periodic prescribed burning in longleaf pine. *Southern J. of Appl. For.*, 11(3): 154-157.

Brown, A.A. & Davis, K.P. 1973. *Forest fire: control and use* (2nd ed.), p. 584. New York, McGraw-Hill.

Croker, T.C., Jr. 1967. Crop-seedling method for planning brownspot burns in longleaf pine. *J. of For.*, 65(7): 488.

Golden, M.S. 1987. *Development and evaluation of low-cost systems for artificial regeneration of pine*. Ga. For. Res. Pap. 71. Macon, Ga, Georgia Forestry Commission.

Grano, C.X. 1970. *Eradicating understory hardwoods by repeated prescribed burning*. Res. Pap. SO-56. New Orleans, La: US Dept of Agriculture, Forest Service, Southern Forest Experiment Station.

Greene, T.A. & Shilling, C.L. 1987. Predicting girdling probability for pine and hardwood saplings in low-intensity backfires. *Forest Sci.*, 33(4): 1010-1021.

Hough, W.A. 1968. *Fuel consumption and fire behavior of hazard reduction burns*. Res. Pap. SE-36. Asheville, NC, US Dept of Agriculture, Forest Service, Southeastern Forest Experiment Station.

Johansen, R.W. 1968. Fire control considerations in pine plantations. In *Proc. Seventh Forestry Forum*. Auburn, Al., Auburn University.

Johansen, R.W. 1981. Windrows vs. small piles for forest debris disposal. *Fire Management Notes*, 42(2): 7-9.

Johansen, R.W. 1984. *Prescribed burning with spot fires in the Georgia Coastal Plain*. Ga. For. Res. Pap. 49. Macon, Ga, Georgia Forestry Commission.

Johansen, R.W. 1987. *Ignition patterns and prescribed fire behavior in southern pine stands*. Ga. For. Res. Pap. 72. Macon, Ga, Georgia Forestry Commission.

Johansen, R.W. & Wade, D.D. 1987. An insight into thinning young slash pine stands with fire. In *Proc. Fourth Biennial Southern Silvicultural Research Conference* (1986, Atlanta, Ga.), p. 103-106. Gen. Tech. Rep. SE-42. Asheville, NC, US Dept of Agriculture, Forest Service, Southeastern Forest Experiment Station.

Johansen, R.W. & Wade, D.D. 1987. Effects of crown scorch on survival and diameter growth of slash pines. *Southern J. of Appl. For.*, 11(4): 180-184.

Lavdas, L.G. 1986. *An atmospheric dispersion index for prescribed burning*. Res. Rep. SE-256. Asheville, NC, US Dept of Agriculture, Forest Service, Southern Forest Experiment Station.

Lilieholm, R.J. & Hu, Shih-Chang 1987. Effect of crown scorch on mortality and diameter growth of 19-year-old loblolly pine. *Southern J. of Appl. For.*, 11(4): 209-211.

Lotan, J.E. *et al.* 1981. *Effects of fire on flora: a state of knowledge review*. Gen. Tech. Rep. WO-16. Washington, DC, US Dept of Agriculture, Forest Service.

Lunsdford, J. 1987. Prescribed fire in the southeast--five steps to a successful burn. *Fire Management Notes*, 48(3):30-35.

Lyon, L.J. *et al.* 1978. *Effects of fire on fauna: a state of knowledge review*. Gen. Tech. Rep. WO-13. Washington, DC, US Dept of Agriculture, Forest Service.

Martin, R.E. *et al.* 1979. *Effects of fire on fuels: a state of knowledge review*. Gen. Tech. Pap. WO-13. Washington, DC, US Dept of Agriculture, Forest Service.

McKevin, M.R. & McKee, W.H., Jr. 1986. Long-term prescribed burning increases nutrient uptake and growth of loblolly pine seedlings. *Forest Ecology & Management*, 17(4): 245-252.

McNab, W.H. 1976. *Prescribed burning and direct-seeding old clearcuts in the Piedmont*. Res. Note SE-229. Asheville, NC, US Dept of Agriculture, Forest Service, Southeastern Forest Experiment Station.

McPherson, G.R., Rasmussen, G.A., Wright, H.A. & Britton, C.M. 1986. *Getting started in prescribed burning*. Management Note 9. Lubbock, Tex., Texas Tech University, Range and Wildlife Management. Dept.

Mobley, H.E. & Kerr, E. 1973. *Wildfire versus prescribed fire in the southern environment*. Atlanta, Ga, US Dept of Agriculture, Southern Area, Div. State and Private Forestry.

Rothermel, R. 1983. *How to predict the spread and intensity of forest and range fires*. Gen. Tech. Rep. INT-143. Ogden, Utah, US Dept of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

Sackett, S.S. 1975. Scheduling prescribed burns for hazard reduction in the Southeast. *J. of For.*, 73(3): 143-147.

Sandberg, D.W. *et al.* 1979. *Effects of fire on air: a state of knowledge review*. Gen. Tech. Rep. WO-9. Washington, DC, US Dept of Agriculture Forest Service.

Schroeder, M.J. & Buck, C.C. 1970. *Fire weather*. Agric. Handb. 360. Washington, DC, US Dept of Agriculture, Forest Service.

Tiedemann, A.R. *et al.* 1979. *Effects of fire on water: a state of knowledge review*. Gen. Tech. Rep. WO-10. Washington, DC, US Dept of Agriculture, Forest Service.

US Dept of Agriculture, Forest Service, Southeastern Forest Experiment Station. 1971. *Proc. Prescribed Burning Symposium*. (Charleston, SC). Asheville, NC.

US Dept of Agriculture, Forest Service, Southeastern Forest Experiment Station. 1976. *Southern forestry smoke management guidebook*. Gen. Tech. Rep. SE-10. Asheville, NC.

US Dept of Agriculture, Forest Service. 1977. *Fire by Prescription Symposium* (1976, Atlanta, Ga). Washington, DC.

US Dept of Agriculture, Forest Service, Southeastern Forest Experiment Station. 1985. *Prescribed fire and smoke management in the South: proceedings of a symposium* (1984, Atlanta, Ga). Asheville, NC.

Villarrubia, C.R. & Chambers, J.L. 1978. Fire, its effect on growth and survival of loblolly pine, *Pinus taeda. L. Louisiana Acad. of Sci.*, 41: 85-93.

Wade, D.D. 1983. Fire management in the slash pine ecosystem. In *Proc. the Managed Slash Pine Ecosystem*. (1981, Gainesville, Fla) p. 203-227, 290-294, 301. University of Florida, School of Forest Resources and Conservation.

Wade D.D. 1986. Linking fire behavior to its effects on living plant tissue. In *Proc. of the 1986 Society of American Foresters National Convention* (1986, Birmingham, Ala), p. 112-116. Bethesda, Md, Society of American Foresters.

Wade, D.D. & Johansen, R.W. 1986. *Effects of fire on southern pine: observations and recommendations*. Gen. Tech. Rep. SE-41. Asheville, NC, US Dept of Agriculture, Forest Service, Southeastern Forest Experiment Station.

Wade, D.D. & Lewis, C.E. 1987. Managing southern grazing ecosystems with fire. *Rangelands*, 9(3): 115-119.

Wade, D.D. & Wilhite, L.P. 1981. Low intensity burn prior to bedding and planting slash pine is of little value. In *Proc. First Southern Silvicultural Research Conference* (1980, Atlanta, Ga), p. 70-74. Gen. Tech. Rep. SO-34. New Orleans, La, US Dept of Agriculture, Southern Forest Experiment Station.

Waldrop, T.A. *et al.* 1987. *Long term studies of prescribed burning in loblolly pine forests of the Southeastern Coastal Plain*. Gen. Tech. Rep. SE-45. Asheville, NC, US Dept of Agriculture, Forest Service, Southeastern Forest Experiment Station.

Wells, C.G. *et al.* 1979. *Effects of fire on soil: a state of knowledge review*. Gen. Tech. Rep. WO-7. Washington, DC, US Dept of Agriculture, Forest Service.